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SOIL SOLAR HEATING

at the Colorado State Forest Service Nursery

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SOIL SOLAR HEATING FOR REDUCTIONS OF POPULATIONS OF *PYTHIUM* SPP., *FUSARIUM* SPP., AND WEEDS AT THE COLORADO STATE FOREST SERVICE NURSERY, FORT COLLINS, COLORADO

by

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ABSTRACT

An evaluation of solar heating of soil for reductions of populations of *Pythium* spp., *Fusarium* spp., and weeds was begun at the Colorado State Forest Service Nursery, Fort Collins, Colorado, in the summer of 1982. Six 3.7 m by 61 m field plots were established: three covered with 0.03 mm clear polyethylene and three left uncovered as checks. Tarps were removed after 55 days (July 2 to August 25). Buried thermographs indicated that soil temperatures under tarps averaged 9°C higher than those of check plots; soil temperatures at 15 cm exceeded 41°C under the tarps. Soil samples were collected for analyses before and after solar heating, and the following spring. No solar heating effect was evident in soil analyses for percent $CaCO_3$, acid-extractable P, organic matter, or pH. Significant ($P<0.05$) reductions in population levels of *Pythium* spp., *Fusarium* spp., and weeds were achieved through solar heating. Although the pathogenicity of the species of *Pythium* and *Fusarium* encountered were not determined in this study, repeated heavy losses to damping-off in the study area have been associated with these fungi. By April 1983, weed populations had returned to pre-treatment levels because of spread of seed onto solar heated plots from adjacent areas. Population levels of *Pythium* spp. decreased over the winter in all plots, while population levels of *Fusarium* spp. increased greatly from August to April in check plots, but only slightly in solar heated plots.

INTRODUCTION

Weeds and damping-off fungi often cause significant seedling losses in forest tree nurseries. Chemical fumigation of the soil is the best control method at present because fungal pathogens and weeds are almost eradicated in a single application (Gillman, 1977). Although soil fumigation in forest nurseries is cost effective (Landis *et al.*, 1976), many kinds of desirable organisms such as mycorrhizal fungi also are destroyed (Munnecke and Van Gundy, 1979). In addition, fumigation chemicals are hazardous, requiring special handling and disposal procedures.

A less expensive and less hazardous method for control of soil-borne pests is solar heating. Solar heating of soil (also referred to as solarization or solar pasteurization) is a recently developed technique in which moist soil is covered with clear polyethylene tarp for several weeks during the hottest part of the growing season for control of soil-borne pathogens and weeds (Katan *et al.*, 1976).

In some locations, the polyethylene film allows solar radiation to increase soil temperatures to over 40°C at 30 cm depth (Pullman *et al.*, 1981b), chiefly by eliminating evaporation and partly by the greenhouse effect (Mahrer, 1979). Continuous or repeated sub-lethal temperatures under moist conditions over long periods either kill pathogenic fungi directly or weaken them so they cannot compete effectively with saprophytes. In laboratory tests, 90% of the propagules of *Verticillium dahliae* Kleb. died after 2 hours at 45°C or after 7 days at 38.5°C in natural field soil, while in pure culture at 45°C, 7 hours were required for 90% mortality (Pullman *et al.*, 1981a). Plant pathogens are apparently more sensitive to elevated temperatures than are saprophytes. Mycorrhizal fungi such as *Glomus fasciculatus* (Thaxter) Gerd. & Trappe can survive solar heating and colonize crop roots (Pullman *et al.*, 1981b). Solar heating of soil alters the balance of microorganisms to the detriment of plant pathogens, and thus solar pasteurization can be considered an integrated pest management technique (Katan, 1980).

Solar heating has been effective against a variety of pathogens. In Israel, the fungi, *V. dahliae, Fusarium oxysporum* Schlect, *Rhizoctonia solani* Kuehn, and *Pythium* spp., and the nematodes *Pratylenchus thornei* Sher & Allen and *Ditylenchus* sp. have been controlled on a variety of agricultural crops through solar heating (Grinstein *et al.*, 1979; Katan *et al.*, 1976; Solarization Research Team, 1981). Annual weeds, broomrape (*Orobanche* spp.), and many perennial weeds have also been greatly reduced (Jacobsohn *et al.*, 1980; Horowitz *et al.*, 1983). In California, *V. dahliae, Pythium* spp., *Thielaviopsis basicola* (Berk. & Br.) Ferr., *R. solani*, and many weeds were controlled with solar heating for agricultural crops and pistachio (Pullman *et al.*, 1981b; Ashworth and Gaona, 1982). Soil solar heating reduced *Phytophthora cinnamomi* Rands and *F. oxysporum* in buried *Pinus radiata* roots in Australia (Old, 1981). Several studies showed that disease reduction was still evident the second growing season after solar heating (Katan *et al.*, 1981; Pullman *et al.*, 1981b).

Solar heating may affect the soil chemistry; increases in nitrate and ammonium nitrogen, potassium, calcium, magnesium, chloride, and phosphate in the soil solution have been reported (Stapleton *et al.*, 1983; Chen and Katan, 1980). Disease reduction and increase in soluble minerals contribute to the increased growth response observed in crops grown in solar heated soil.

Solar heating of soil in conifer nurseries has been evaluated recently in a few areas of the United States. Preliminary results at the Iowa State Nursery (Croghan, 1983, personal communication) indicate some reduction in populations of *Fusarium* sp. and nematodes from solar heating. Cooley (1983), in trials at the Bend Forest Nursery in eastern Oregon, found that populations of *Fusarium* sp. were reduced an average of 32% by solar heating, but tree seedling survival after 10 weeks was similar in check and solar heated plots. Zarnstorff (1983) in Wisconsin found no significant reductions in populations of *F. oxysporum, R. solani,* or *Cylindrocladium floridanum* Sobers & Seymour after solar heating. McCain and others (1982) found that *F. oxysporum* was eliminated in soil down to 10 cm depth and reduced in soil between 10 and 20 cm, while *Macrophomina phaseolina* (Tassi) Goid. survived at all depths after solar heating in a northern California nursery near Placerville.

A study was undertaken to assess the effectiveness of solar heating in reducing population levels of *Pythium* spp., *Fusarium* spp., and weeds at a conifer nursery in the Rocky Mountain Region, where repeated heavy losses to damping-off have been associated with these fungi.

MATERIALS AND METHODS

The present evaluation took place at the Colorado State Forest Service (CSFS) Nursery. The nursery is located on the western edge of Fort Collins, Larimer County, Colorado, at 1561 m (5120 ft) elevation. Soils in the area are well developed, derived from the Slocum alluvium (Pleistocene), a cobble and boulder gravel (Colton, 1978). The soil in the study area was sandy clay loam (52% sand, 25% silt, and 23% clay) mapped as Altvan Sandy Loam in the Kim Loam Series by the Larimer County Soil Survey (Moreland, 1980). Munsell colors for the soil in the Nursery study area were grayish brown (7.5YR 5/2) dry, and dark brown (7.5YR 3.3) moist.

Tree seedling production began at the nursery in the middle 1960's. Study plots were set up in a nursery block in which an entire spruce planting had been recently plowed under due to excessive losses to damping-off. The nursery block is 91 m by 61 m (300 ft by 200 ft), slopes gently (1-3%) to the southeast, and has never been fumigated.

Six plots, 3.7 m by 61 m (12 ft by 200 ft), were arranged in a randomized block design parallel with nursery beds. Three plots were covered with 0.03 mm (2 mil) polyethylene film for solar heating, and three plots were left uncovered as checks. Buffer strips were left between treatment plots and between the edge of the block and the plots. Plot layout is

illustrated in Figure 1. The block was disked and harrowed in June, 1982, and all plots were established June 30. Following soil irrigation to field capacity, tarps were placed on solar plots July 2, anchored at the edges with soil, and removed after 55 days. A 14 kg (30 lb) roller was rolled across the surface of each tarp in an attempt to achieve maximum contact between the soil and the tarp (Plate 2A).

Before solar heating, six Peabody Ryan model J thermographs were buried (Plate 2B). One thermograph was buried at 8 cm and one at 15 cm along the center of each of two solar and one check plot at a random distance from the ends. Thermograph positions are indicated in Figure 1. The thermograph for the 8 cm depth in the check plot was not buried until July 12 due to equipment malfunction. Flagging was tied to each thermograph and attached to a stake placed at the edge of the plot to indicate thermograph position (Plate 2C).

Soil samples for laboratory assay of populations of *Pythium* spp., *Fusarium* spp., and viable weeds were taken in late June before tarping, in late August after tarps were removed, and the following April. Soil was not sampled from identical locations each time. Four soil samples--composites of six 15 cm soil probe cores taken in a 30 cm radius--were collected at 12 m intervals along the center of each of the six plots, the first sample spot being chosen at random. These soil samples were assayed for *Pythium* spp. as in Hendrix and Kuhlman (1965),and for *Fusarium* spp. as in Nash and Snyder (1962).

Analyses of covariance were performed and minimum significant ranges computed for the means (by Tukey's honestly significant difference method, Sokal and Rohlf, 1981) for population levels of *Pythium* spp. and *Fusarium* spp. For comparison purposes, population levels of *Pythium* spp. of less than 10 propagules per gram of soil (PPG) were considered low, 10 to 40 PPG moderate, and over 40 PPG high. Population levels of *Fusarium* spp. of less than 1000 PPG were considered low, 1000 to 4000 PPG moderate, and over 4000 PPG high.

Soil for weed tests was collected from the top 2.5 cm of soil from within a 929 cm^2 frame placed at 12 m intervals (four per plot) for each of the six plots (Plate 2D). This soil was poured in 24 aluminum foil pans, watered as needed and kept in a Scherer Environmental Chamber at 12 hours light at 25°C, and 12 hours dark at 18°C. After two weeks, weed seedlings were counted. Minimum significant ranges for the means of weed seed germination counts were computed by Tukey's method (Sokal and Rohlf, 1981). For each weed soil sample taken in August and April, the percent of the area within the frame shaded by the weed canopy was visually estimated and recorded as percent weed cover. Significant differences in percent weed cover were determined by analysis of variance.

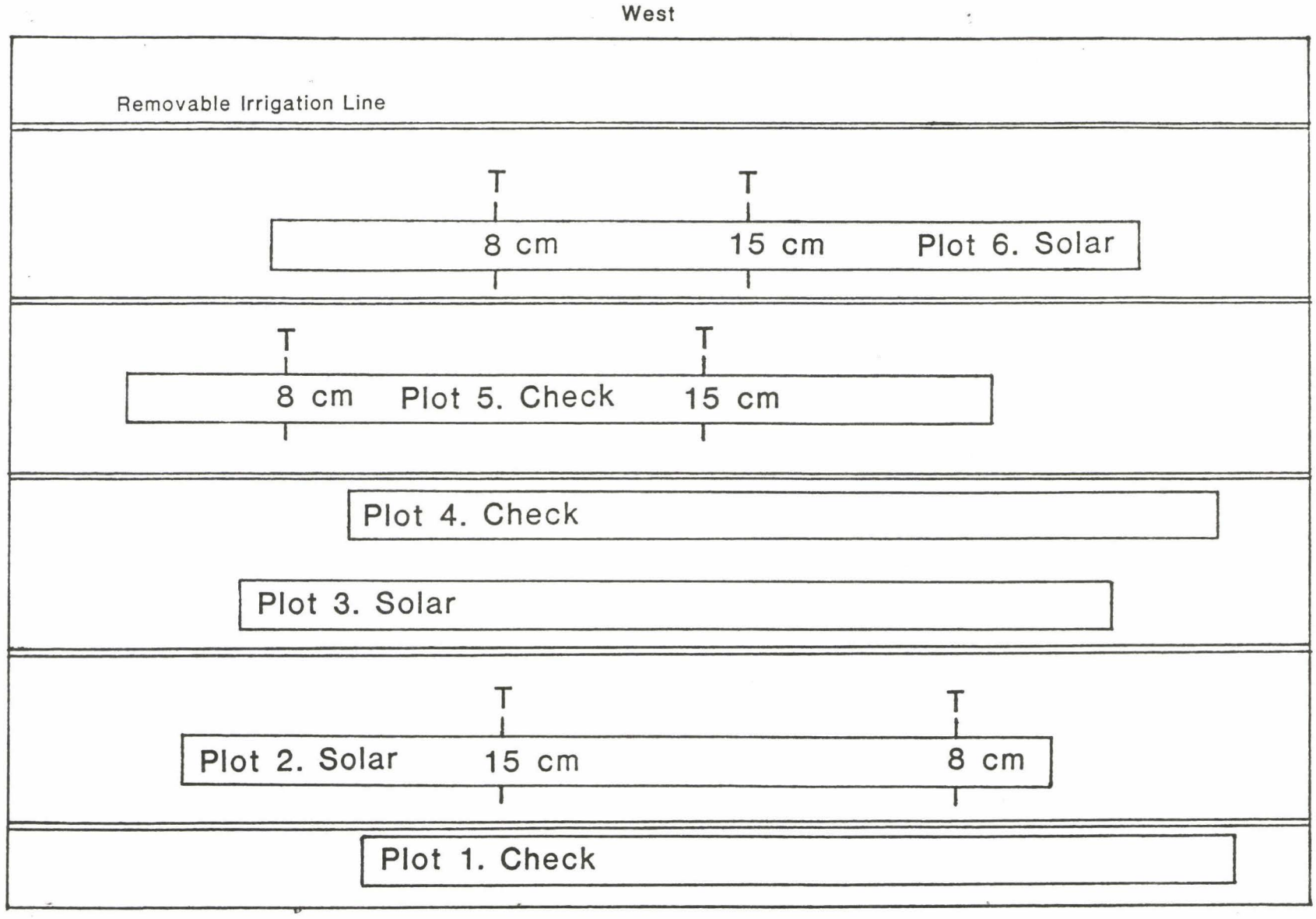


Figure 1. Plot layout and thermograph positions (T) and depths at the CSFS Nursery, Fort Collins, 1982.

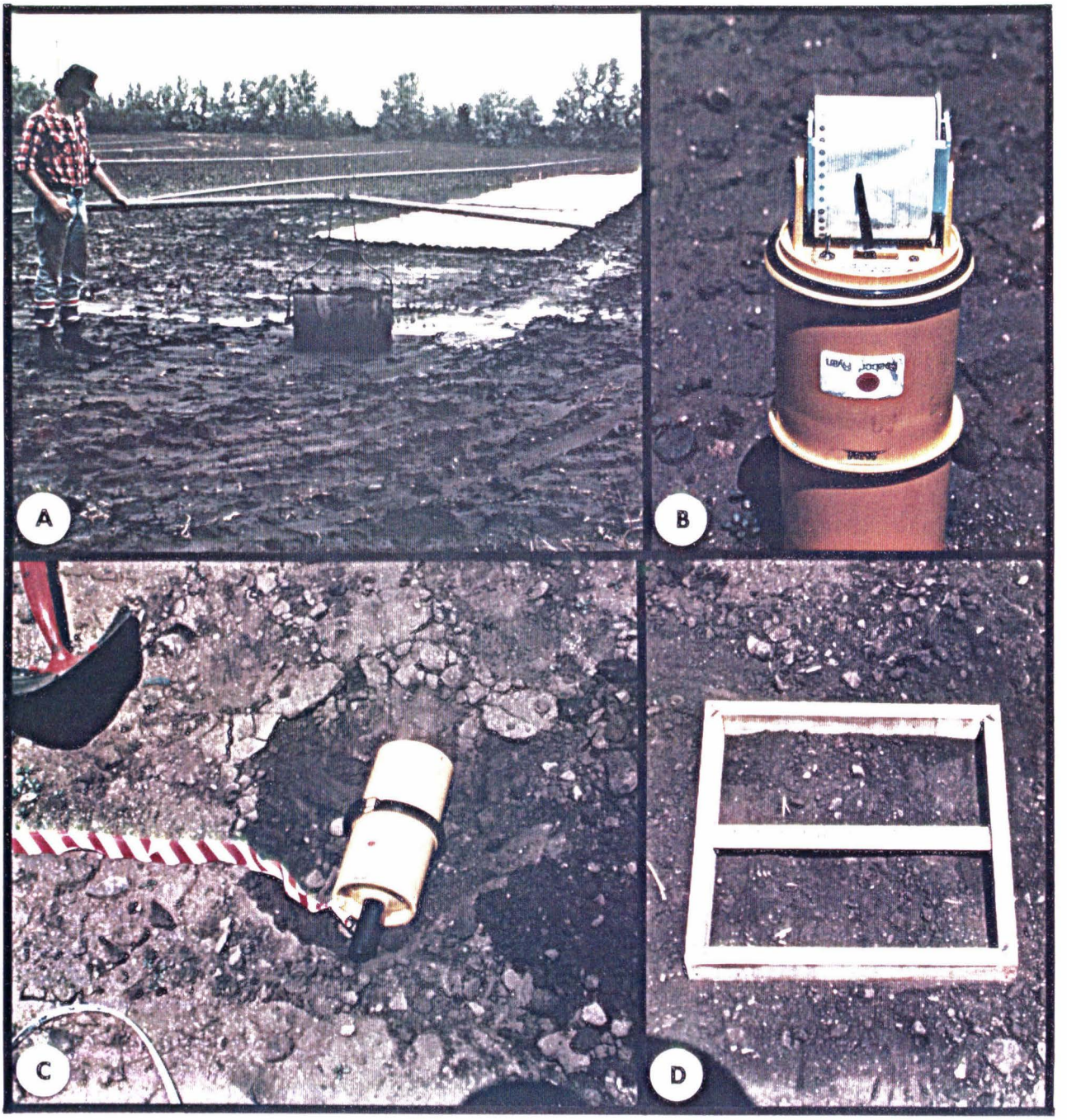
Plate 2

A. Roller used to smooth polyethylene tarps onto wet soil at the CSFS Nursery, 1982.

B. Open thermograph revealing needle on chart.

C. Thermograph in position with center of sensor at 8 cm depth, ready for burial.

D. Wooden frame used as border for weed sampling sub-plots.


A
B
C
D

Additional analyses were performed on four soil samples remaining from the fungal assay samples. These samples were from the farthest upslope (northwest end of Solar plot 6) and farthest downslope (southeast end of Check plot 1) locations, taken in June and August. Analyses included acid-extractable phosphorus determination by spectrophotometer, pH determination in water and in calcium chloride, and percent organic matter determination by the Walkley-Black method. These methods are described in Black *et al.*, 1965. Percent calcium carbonate was determined by the gasometric method with the Chittick apparatus (Dreimanis, 1962).

RESULTS

Solar heating resulted in a significant ($P<0.05$) decreases in population levels of *Pythium* spp. and *Fusarium* spp., in numbers of germinated weed seedlings, and in weed cover. Although fungal and weed population levels were quite variable within plots, the effect of solar heating was still significant.

Analysis of covariance between values for check and solar heated plots in August, adjusted by the June (before solar heating) values as covariates, showed a significant ($P<0.01$) difference in population levels of *Pythium* spp. (Table 1). Population levels of *Pythium* spp. dropped an average of 60% from high to moderate due to solar heating, while check plot levels remained high from June to August. In samples from the following spring (April 1983), *Pythium* spp. levels had decreased over the winter in all plots--levels in check plots fell from high to moderate, while levels in solar plots fell from moderate to low (Table 2).

Table 1. Analysis of covariance table for propagules per gram of soil of *Pythium* spp. in check and solar heated plots (August values) adjusted by pre-treatment (June) values as covariates.

Source of Variation	Sum of Squares	df	Mean Square	F
Covariates	1423.4	1	1423.4	2.20
Solar Heating Effect	7360.3	1	7360.3	11.35 **
Within Group Error	13617.0	21	648.4	
Total	22400.7	23		

**Significant at $P<0.01$

Minimum significant ranges computed for the means of population levels of *Fusarium* spp. show a significant ($P<0.05$) reduction due to solar heating, when comparing before and after levels in solar plots. Check and solar plot population levels were not statistically different in August (Figure 3). Population levels of *Fusarium* spp. dropped an average of 74% from moderate to low due to solar heating, while levels in check plots remained moderate. Between August and the following April, *Fusarium* spp. population levels increased in all plots, but while levels in check plots increased from moderate to high, levels in solar plots remained low (Table 2). The major species encountered were *F. oxysporum* and *F. solani* (Mart.) Sacc.

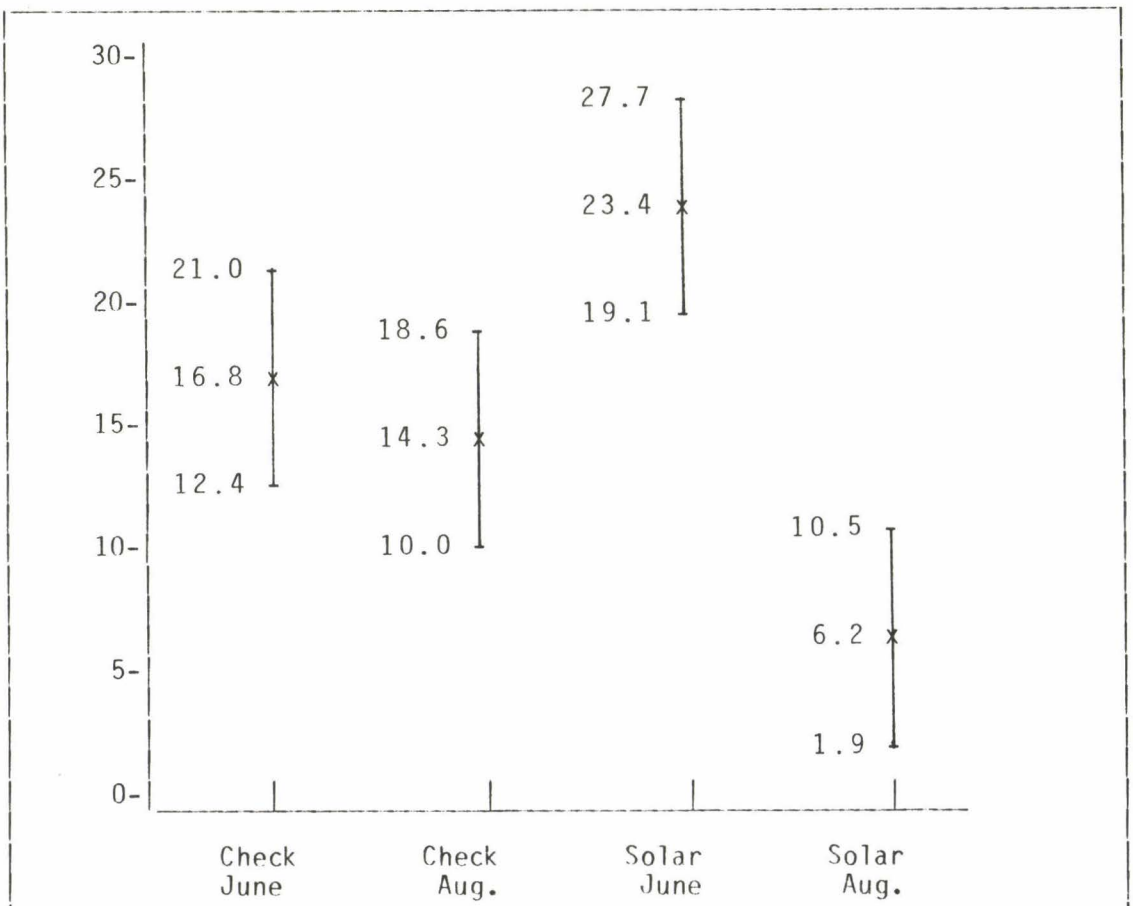


Figure 3. Minimum significant ranges (MSR=8.6, $P<0.05$) bracketed around sample means for average number of colonies per sample for *Fusarium* spp. in check and solar plots at the CSFS Nursery, 1982. (Where treatment brackets overlap on the vertical axis, there is no significant difference between means.)

Table 2. Means for population levels of *Pythium* spp. and *Fusarium* spp. (as propagules per gram of soil, PPG) and for germinated weed seeds, by plot for samples from the CSFS Nursery, Fort Collins, 1982-83.

A. *Pythium* spp. average PPG for 4 samples per plot.

Plot	June,1982	August,1982	April,1983
1. Check	61.4	59.0	25.5
4. Check	68.3	68.1	19.3
5. Check	61.7	47.6	11.1
Grand Mean	63.8	58.2	18.6
2. Solar	35.9	9.3	12.4
3. Solar	47.4	25.8	7.7
6. Solar	84.1	31.2	3.7
Grand Mean	55.8	22.1	7.9

B. *Fusarium* spp. average PPG for 4 samples per plot.

Plot	June,1982	August,1982	April,1983
1. Check	2267	1700	8200
4. Check	2533	2267	12200
5. Check	1900	1733	8833
Grand Mean	2233	1900	9744
2. Solar	2766	433	867
3. Solar	3300	1267	267
6. Solar	3300	767	833
Grand Mean	3122	822	656

C. Weed seed germination, counts for 4 samples per plot.

Plot	June,1982	August,1982	April,1983
1. Check	26	23	6887
4. Check	75	11	2395
5. Check	58	11	9312
Grand Mean	53	15	6198
2. Solar	139	4	65
3. Solar	27	0	230
6. Solar	130	0	68
Grand Mean	99	1.3	121

The significant differences ($P<0.05$) in weed seed germination counts as determined by minimum significant ranges computed for the means are illustrated in Figure 4. Weed population levels dropped almost 99% due to solar heating, although levels in check and solar plots were not statistically different in August.

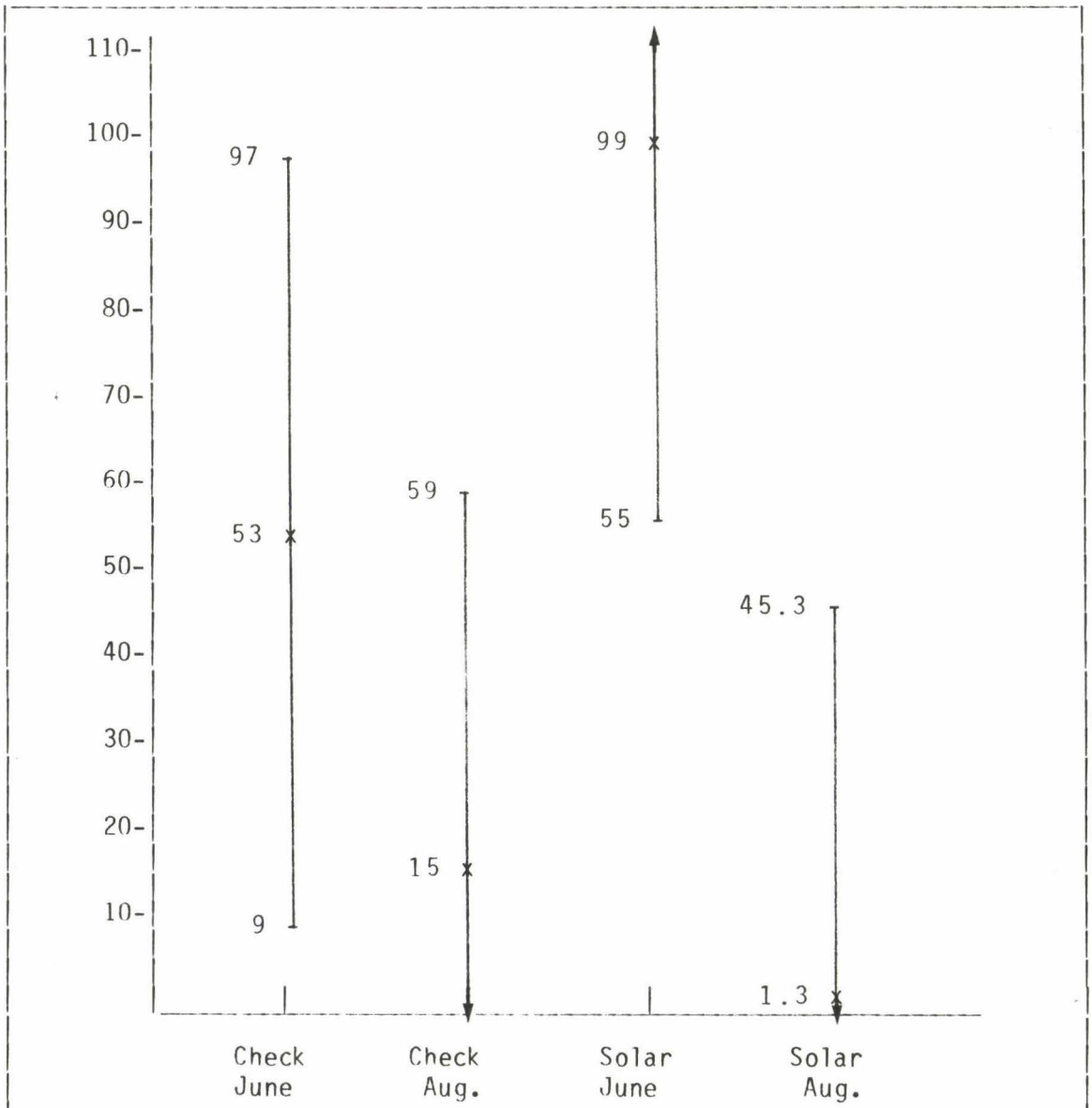


Figure 4. Minimum significant ranges (MSR=88, $P<0.05$) bracketed around means for average number of weed seedlings germinated per plot for check and solar plots at the CSFS Nursery, 1982. (Where treatment brackets overlap on the vertical axis, there is no significant difdifference between means.)

By August most of the weed seeds in the check plots had germinated and matured, and a new crop of weed seeds were accumulating on the ground. The major weed species growing in the check plots and adjacent areas were common purslane (*Portulaca oleracea* L.), clammy groundcherry (*Physalis heterophylla* Nees), and redroot pigweed (*Amaranthus retroflexus* L.). Very little weed growth occurred under the solar tarps (Table 2, Plate 5A), although some purslane was growing slowly in spots. Some dead weed seedlings were observed when tarps were removed. The significant difference ($P<0.001$) in percent weed cover as determined by analysis of variance is shown in Table 3. Weed cover in solar plots averaged 97% less than in check plots. By April, 1983, germination of weed seed samples showed that potential weeds had increased to levels greater than in June samples in check plots, and had returned to pretreatment levels in solar plots, due to intense weed seed production in check plots and adjacent areas (Plate 5B).

Table 3. Average percent August weed cover per plot and analysis of variance table for plots at the CSFS Nursery, 1982.

Check	1.C	89 %	Solar	2.S	6 %
	4.C	89		3.S	0.1
	5.C	85		6.S	4
Grand Mean		88	Grand Mean		3

Source of Variation	Sums of Squares	df	Mean Squares	F
Solar Heating Effect	42617.87	1	42617.87	295.1***
Within Group Error	3177.23	22	144.42	
Total	45795.10	23	1991.09	

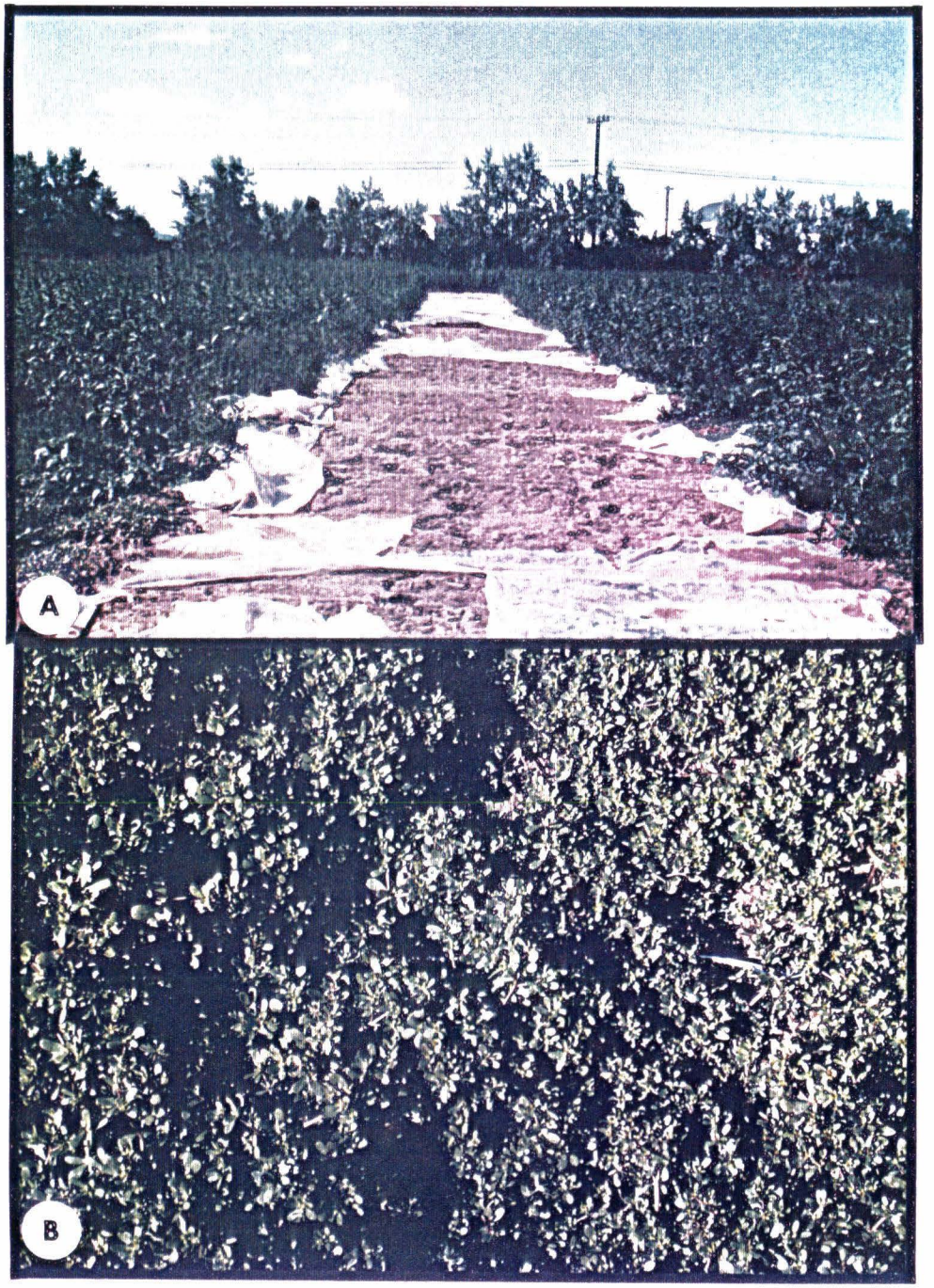
***Significant at $P<0.001$

Polyethylene tarps required occasional mending of holes, mostly from deer stepping on tarps to drink from puddles on the surface. Thick clear plastic tape (Scotch ® Cat. 191) remained supple and intact three weeks after mending. Pieces of polyethylene glued over holes was less satisfactory for mending, because the glue (Duro ® Plastic Mender PM-9) became brittle in the sun and did not hold after two weeks. The tarps remained essentially intact until August 23 (after 54 days) when high winds shredded the then brittle plastic (Plate 5A).

Plate 5

A. Solar plot in late August, 1982, after the wind shredded the polyethylene; with heavy weed growth in adjacent areas at the CSFS Nursery.

B. Heavy growth of purslane shading the location of the check plot thermograph at the CSFS Nursery, 1982.


A
B

Because the recording range of the thermographs was 10-40°C, temperatures above 41°C were off-scale. Table 4 gives average temperature lows, highs, hours the temperature remained within 1°C of the high or low, and the temperature range. The average high temperatures given for the solar heated plots are conservative, because the highest value used in the computation was 41°C. Temperatures were highly variable. Under the solar tarps, the thermographs at 15 cm did not indicate temperatures greater than 41°C until late in the third week, while temperatures at 8 cm exceeded 41°C the first day. In check plots, the highest temperature recorded by the thermograph at 15 cm was 34.2°C, and by the 8 cm 38.5°C. Soil temperatures under the tarps averaged 9°C higher than those of check plots. July temperatures did not differ appreciably from those achieved in August in solar plots. However, for check plots, the August highs averaged several degrees lower than those in July, probably due to shading by weeds (Plate 5B).

Table 4. Thermograph average high and low temperatures (°C), ranges, and hours maintained within 1°C of high or low for plots at the CSFS Nursery, 1982.

Plot & Depth	6.Solar 8 cm	2.Solar 8 cm	6.Solar 15 cm	2.Solar 15 cm	5.Check 8 cm	5.Check 15 cm
Low	22.8	23.4	26.2	26.0	18.3	20.0
Hours	4.4	3.6	6.2	4.4	5.0	6.2
High	39.1	40.1	32.9	36.4	28.2	27.1
Hours	4.6	5.6	6.3	4.9	4.8	6.0
Range	16.3	16.7	7.0	10.1	9.7	7.2

Results from the chemical analyses of the soil samples are summarized in Table 5. Phosphorous and organic matter increased over the summer in both the check and solar heated samples. The check sample contained less $CaCO_3$, salt, phosophorus, and organic matter, and lower pH than the solar heated sample. These apparent differences in the chemical analyses are not solar heating effects, because the differences upslope (solar) and downslope (check) are evident in the June samples before solar heating. The greater leaching downslope may be due to larger quantities of water passing through the soil in the southeast corner of the Nursery Block, where puddling occurs after heavy rain or excess irrigation, compared with the upslope corner which dries out more quickly.

Table 5. Results from chemical analyses for soil samples from two plots from the CSFS Nursery, Fort Collins, 1982.

	Solar June	Check June	Solar August	Check August
% $CaCO_3$	4.9	0	-	-
% Gypsum	0	0	0	0
% Salt	0.09	0.05	-	-
mg % P acid extractible	50.6	36.0	58.0	44.4
% Organic Carbon	0.85	0.6	1.3	1.2
% Organic Matter	1.5	1.0	2.2	2.0
pH in H_2O	7.9	6.4	7.8	6.6
pH in $CaCl_2$	7.6	6.1	7.7	6.3

DISCUSSION

Results in the solar plots show that solar heating of the soil can be effective in reducing populations of damping-off fungi and weeds at high elevation Colorado nurseries. Weed populations would not become re-established by the following spring if the entire block were covered with tarp for solar heating, and adjacent areas were periodically mown or disked. Populations levels of *Pythium* spp. and *Fusarium* spp. were significantly reduced, on the average, by solar heating, although the extent of reduction and the temperatures achieved were quite variable within the plots. Katan (1981) suggested that the fungal assay as used in this evaluation might give inflated counts because a weakened propagule may give rise to a colony in the assay, but may not survive under field conditions.

In the present evaluation, the soil gradually became drier as weeks passed and was fairly dry by late August, but should have been sufficiently moist under the tarps for the first five or six weeks (Grinstein *et al.*, 1979). In addition, the soil was not in the best of tilth. The soil surface was cloddy and irregular, which increased the size and frequency of air pockets and shadows, and may have contributed to the variation in temperatures achieved. Better soil preparation might afford less variation in fungal population reduction.

Both fumigation and solar heating require favorable weather and the same use of tractor, personnel, tarps, and rollers. With solar heating the safety hazards and cost of handling the toxic fumigant are eliminated. The cost-savings on the price of the fumigant is conservatively estimated at $350 per acre (Hinz, 1984). A disadvantage of solar heating is the attention required from nursery personnel to assure against wind and other damage to tarps during the treatment period. Also, solar heating requires that the land being treated be out of production for most of the summer preceding planting.

The ultimate test of the effectiveness of soil solar heating is, of course, survival of planted trees. A spring planting of *Pinus ponderosa* Laws. was planned for this evaluation to reveal the effect of residual fungal populations, but weather and nursery problems delayed planting in the study area until too late in the season for any meaningful seedling mortality information. Based on laboratory tests, the good control of weeds and the reductions in populations of *Pythium* spp. and *Fusarium* spp. afforded by soil solar heating makes the technique of some use, especially where fumigation is not accepted or cannot be used.

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